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Anisotropic Projector*

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An optical projector having different magnifications, 5 \times and 50 \times , in two rectangular directions is described. Although the device is designed principally for rapid measurement of cloud-chamber track curvatures, it has been applied to various situations in which plane-to-plane imaging at constant magnification is desired. Simple plano-convex cylindrical lenses are used as the image-forming elements. These give quite satisfactory linearity and resolution at the maximum magnification.

1. INTRODUCTION

IN many experimental situations, one is confronted with the problem of detecting and measuring the deviation of a nearly straight curve from a straight line: the measurement of the curvatures, small-angle scatterings, or scattering through plates of individual cloud chamber tracks, the scanning of many parallel "beam" tracks in a cloud chamber (or bubble chamber) for small-angle deflections, the measurement of multiple scattering of tracks in nuclear emulsions, the examination of ionization chamber film records for small bursts, the searching of oscillograph records for small deflections, and many other similar cases can be cited. In all such problems, a straight line must be provided for comparison with the curve in question, and some means of measuring the departure of the curve from this line must be available. One standard procedure is to use a microscope comparator with very accurate stage motions to follow the curve point by point, recording the screw readings for later analysis. Although such a scheme is basically quite sensitive and accurate, it is also very time consuming, and in certain applications may actually be more sensitive than necessary. Furthermore, one's field of vision along the curve is quite restricted at the high magnifications that are necessary for easy measurement of small lateral deviations of the curve, so that certain gross features such as a small angular deviation of the curve may be missed.

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The device described in the following affords another means of accomplishing the stated purpose through the use of an optical system having different longitudinal and lateral magnification factors. In practice this system has been found to reduce the measurement time for cloud-chamber track curvatures by about a factor of ten with negligible, if any, reduction in accuracy. Furthermore, the use of a tenfold magnification ratio in the two directions has the effect of multiplying small angles by a factor of ten, thus making more apparent any small-angle deflections or small offsets in the curve.

2. PRINCIPLE OF OPERATION

An optical device having different magnifications in two rectangular directions has previously been reported.¹ Basically, such a device depends upon the fact that two thin cylindrical lenses with crossed axes act independently of each other. Such a system can provide point-to-point imaging in first order as shown schematically in Fig. 1.

Suppose the total distance from object plane to image plane is D . Then, if the magnification factors are to be m_1 along one axis and m_2 along the axis at right angles, the focal lengths of the cylindrical lenses needed are,

$$f_1 = D / \left(2 + m_1 + \frac{1}{m_1} \right)$$

and

$$f_2 = D / \left(2 + m_2 + \frac{1}{m_2} \right).$$

¹ D. R. Buchele and H. R. Goossens, *Rev. Sci. Instr.* **25**, 262 (1954).

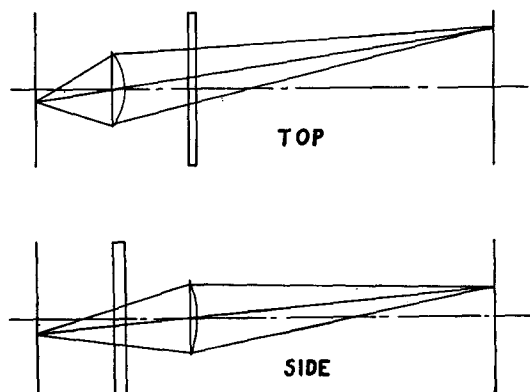


FIG. 1. Schematic illustration of the formation of an image by two cylindrical lenses with crossed axes. The combined action of the two lenses results in point-to-point imaging in first order.

In practice it is desirable to use symmetrical doublets rather than single element lenses. This gives better flatness of field, less chromatic and "spherical" aberration than a single lens, and in addition provides a certain amount of fine adjustment of focal length by varying the element spacing.

In order to provide sufficient illumination through the system, an astigmatic condensing lens arrangement must be used whose focal lines match the two cylinder lens apertures. This is most inexpensively accomplished by using ordinary spherical condensing lenses which would focus the light through a small circular aperture at the more distant cylindrical lens; a single plano-cylinder condenser can then be used to provide the additional convergence needed to bring the beam to a line focus inside the nearer cylindrical lens as well.

3. CONSTRUCTION

The basic arrangement shown in Fig. 1 can, of course, be applied in practice in many different ways. The particular function for which the present device was constructed was to provide an enlarged image of a given cloud-chamber track in such a form that the curvature of this track could be quickly and accurately measured. Because a large number of such tracks were to be processed, it was necessary to pay special attention to the ease and rapidity with which a given track could be mounted, centered, and measured. The present design has proved quite satisfactory in these respects.

The general layout of the optical system is shown in Fig. 2. Our experience with reprojection of cloud-chamber photographs has shown that an image projected upward from below onto a horizontal plate-glass screen is most convenient for sketching and measurement, using a piece of tracing paper fixed to the glass surface. This arrangement permits very close observation and measurement of the image without interfering with the light beam, and the use of tracing paper provides a permanent record which can be kept with the original photograph for later reference. It is

also quite desirable that the operator be able to adjust the position of the film and observe the image at the same time, preferably without having to alter his posture in the process. For these reasons the system was "folded" so that the film and the image are in approximately the same plane. The light thus proceeds downward through the film, through the two crossed cylindrical lenses, reflects from two 45° front-aluminized mirrors which reverse its direction, and finally comes to a focus on the top face of the horizontal plate-glass working surface.

Some of the more important features of the design will now be described.

(a) Light Source and Condensing Lens System

The light source system is mounted on a bridge-like bracket (1) which permits free access to the film plane from all sides for positioning the film. A 150-w projection bulb is mounted upright on a support which permits some motion for centering and focusing. This support also holds a front-aluminized spherical glass reflector (2) behind the bulb. Ventilation holes are provided in the bottom of the light box, and a blackened chimney (3) around the bulb permits escape of air upward past the bulb itself. Suitable baffles, and a 45° bend in the chimney, prevent excessive leakage of light which would tend to reduce the effective contrast at the image plane. A 45° plane mirror (4) serves to direct the horizontal light beam into the downward direction and into a pair of spherical condensing lenses

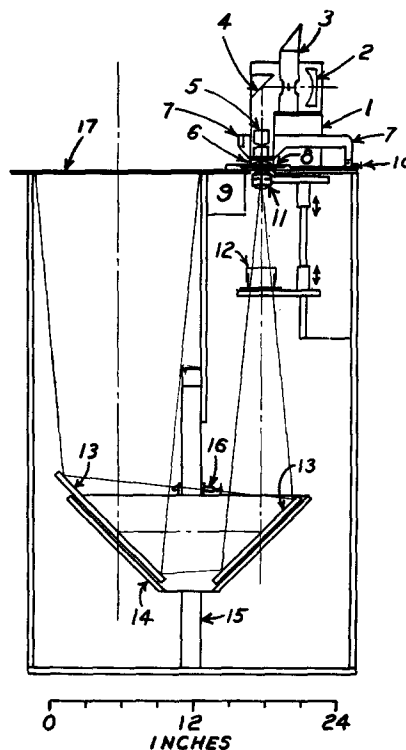


FIG. 2. Side view of optical arrangement of projector.

(5) of rectangular cross section 2 by $5\frac{1}{2}$ in. These were cut with a diamond saw from 6-in. diam., 10-in. focal-length condensers. The bottom plane face of the lower condenser lens is approximately $\frac{1}{2}$ in. above the film plane.

(b) Film Carrier

The film is held, emulsion side down, between two plane glass surfaces. The upper surface is the plane face of a plano-convex cylindrical lens (6) which forms part of the condensing lens system. This lens is 1 in. wide by 5 in. long and has a focal length of 2 in. The film is pressed by the weight of this lens and its hinged mount (7) against the top surface of a 4- by 5-in. glass plate (8) upon whose surface a reticle system may be scribed if desired. The entire film carriage is free to slide horizontally as a unit in a shallow, close-fitting guide groove. It may thus be withdrawn from the optical path so that the film can be viewed directly against a small illuminated viewing plate (9) whose bulb is actuated by a microswitch. This facilitates initial identification and centering of the proper cloud-chamber track. When in projection position, the film carriage is pushed against a fixed reference stop (10).

(c) Objective Lens System

The upper objective (11), which provides the $50\times$ lateral magnification, is composed of two plano-convex cylinder lenses identical with the cylindrical condenser mentioned above. All possible orientations of these two lenses were tried, using various spacings and various diaphragm locations. It was found that the most favorable relationship from the standpoint of flatness of field, angular coverage, freedom from distortion, and freedom from chromatic and spherical aberration, was that of a symmetrical doublet with plane sides facing one another and separated by about $\frac{3}{4}$ in. A $\frac{1}{8}$ -in. wide aperture was built into the rectangular lens mount at the center of symmetry.

The lower objective, (12), which provides the $5\times$ longitudinal magnification, consists of two 2.0-diopter plano-convex cylinder spectacle lens blanks obtained from American Optical Company. These lenses are mounted in a telescoping barrel, so that their equivalent focal length can be adjusted over a sufficient range to permit fine adjustment of the longitudinal magnification factor. These lenses can be rotated with respect to one another to permit alignment of their axes, and the barrel can also be rotated as a unit.

Each objective lens can be moved vertically for focusing, and the upper lens mount is provided with a small amount of rotary motion for adjustment and collimation.

(d) Mirror System and Screen

Two rectangular first-surface mirrors (13) made of $\frac{1}{2}$ -in. polished plate-glass are mounted at a 90° angle

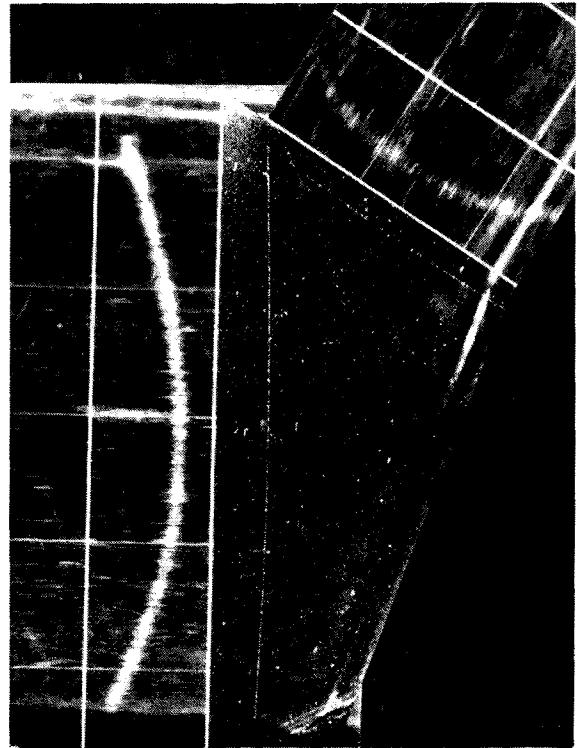


FIG. 3. Comparison of direct enlargement of cloud-chamber tracks with enlargements made with anisotropic projector. The two tracks are secondaries of a neutral V -particle. The anisotropic enlargements shown beside them are at the same longitudinal scale and ten times the lateral scale. The straight lines are the lines of a reticle comprising a gridwork of 1-mm by 1-cm rectangles.

with one another, each being 45° with the vertical, on a wooden mounting which can be slid vertically on two wooden guide rails (15). This motion is used for fine adjustment of the $50\times$ magnification. Clamps (16) are provided for locking the mirror mount to the rails after adjustment.

The screen (17) consists of a rectangular piece of $\frac{1}{4}$ -in. thick polished plate-glass supported on $\frac{1}{16}$ -in. thick rubber. This glass plate abuts into a groove in the $\frac{1}{2}$ -in. thick metal plate on which the optics and film holder are carried, making a virtually dust proof joint. One edge of this glass plate, at the observer's left, is quite smooth and straight, and projects slightly beyond the edge of the wooden support so that a T-square can be used for constructing chords and saggittae on the tracing paper.

4. ADJUSTMENT

Before the final design was fixed, the optical parts were set up on the bench and approximate mounting dimensions for the various components ascertained. On the basis of these dimensions the final device was built, a certain amount of adjustability being provided where necessary for collimation or for setting the magnification factors. The condensing lens system was fixed in position, the only adjustment in focus and

alignment being made by movement of the lamp base.

The system was first assembled and brought into rough alignment and focus. A photographic reticle was inserted, emulsion side up, into the recess provided for the 4- to 5-in. film support glass. This reticle consisted of many rectangles 1 mm by 1 cm in size, and the magnifications were to be adjusted so as to image these rectangles into squares 5 cm on a side.

The 50 \times magnification factor was first set precisely by moving the lower 90° mirror support up or down. Fine adjustment was accomplished by a small screw jack under the mirror mount. When adjusted, these mirrors were lightly clamped with the screw jacks still in position.

The 5 \times magnification was next set by changing the spacing between the two elements of the lower doublet and refocusing as necessary.

The angular relationship between the two objective lenses and the reticle was then adjusted so that the magnified 1-mm spaced lines were parallel to the T-square edge, and the two sets of lines were in sharp focus and perpendicular to each other. (The sharpness of the image depends critically upon the angular relationship of the two objective lenses and can be used as a test for this adjustment.)

Finally, all adjustments were checked and then firmly clamped. The reticle was removed and replaced by a clear 4- by 5-in. glass plate of the same thickness.

5. MEASUREMENT PROCEDURE

To measure the radius of curvature of a cloud-chamber track, the film is inserted into the film carrier emulsion side down and is approximately centered within the 5-mm wide by 5-cm long field of view. The film carrier is then slid into working position and the track image located in the 25-cm square field on the tracing paper screen. Small adjustments of the film are then made so as to bring the magnified image into the desired position for measurements with the two ends of the track image on the same horizontal (i.e., parallel to the T-square) line. Our track images are generally about 5 mm wide at 50 \times magnification. The course of the center of the track is lightly sketched with a sharp drawing pencil. The track is traced in this way several

times in each direction so as to reduce the error due to setting "noise." A chord is then drawn with the T-square, and a perpendicular erected at the center of the chord. The sagitta of the track is measured along this perpendicular. In terms of the half-length x of the chord and the sagitta δ each measured on this sketch, the radius of curvature of the track *on the film* is given by the simple formula

$$R = x^2/\delta + \delta/100,$$

which is exact if the true curve is a circle on the film.

If the track image, or the resulting sketch, show evidence of scattering or distortion, the radius is checked using smaller segments of the track.

The total time required, from insertion of the film into the carrier to the computation of the radius of curvature, is normally four or five minutes.

Figure 3 shows the two secondary tracks of a neutral V-particle, with enlargements of the tracks obtained with the anisotropic projector.

6. PRECISION AND SENSITIVITY

In the application of this projector to various physical problems, the optical resolution obtainable, the magnitude of the aberrations, and the precision with which the magnification can be preset are of interest.

In its present form, the smallest detail that can be resolved at the screen is about 0.25 by 0.1 mm which corresponds to 5 by 20 μ on the film. The resolution appears to be limited by chromatic aberration, and it might be improved by using achromatic lenses.

The third-order aberrations are minimized by restricting the focal ratio of each objective to about $f/10$, by using symmetrical doublets, and by restricting the angular coverage needed through the use of relatively long focal lenses. Thus the 25-cm square field on the screen subtends an angle of only about 10° at the objective lenses. Within this field the third-order aberrations amount to less than about 0.25 mm, or 0.1% of the field diameter.

Direct comparison of distances measured with the projector with those measured using a microscope comparator shows that the two magnifications are accurate to within about 0.1%.